NATIONAL BUREAU OF STANDARDS REPORT

7015

CENTRAL FURNACE CONTROL AND RECORDING FACILITY

by

D. Gross
W. H. Bailey
E. W. Bender
A. F. Robertson

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers. These papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($1.50), available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
1002-00-10820	November 21, 1960	7015

CENTRAL FURNACE CONTROL AND RECORDING FACILITY

Fire Research Section

by

D. Gross
W. H. Bailey
E. W. Bender
A. F. Robertson

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

CENTRAL FURNACE CONTROL AND RECORDING FACILITY

Fire Research Section

by

D. Gross, W. H. Bailey, E. W. Bender, and A. F. Robertson

ABSTRACT

A description is provided of the fire endurance furnace control and program equipment and of equipment currently used for measuring and recording temperature and millivolt signals. A one-hundred channel digital data printout system which has been recently installed is described in some detail. It provides for data readout at the rate of 60 channels per minute. Direct indication of temperatures with the use of chromel-alumel thermocouples is provided in the range of 0-1400°C with an accuracy of ±4°C. Millivolt signals may also be measured over the range of 0-14.00 mv with an accuracy of ±0.04 mv. Provision is made for automatic programming both the number of circuits to be scanned as well as which of these will be measured in terms of temperature, or millivolts.

1. INTRODUCTION

During the last six or eight years, a central control and data recording facility has been used for most of the temperature measurement work performed in the Fire Research Section. Recently, automatic equipment has been installed to permit digital recording of as many as one hundred temperature or millivolt signals. It appears desirable for record purposes, and as an instructional guide to staff members, to provide a brief description of the complete system.

2. CENTRAL CONTROL AND RECORD FACILITY

As shown in the block diagram, Fig. 1, the facility consists of five major components:

1. The instrument jack board and associated wiring,

2. The potentiometric recording unit,

3. The potentiometric indication unit,

4. The automatic digital recording unit, and

5. The furnace program control unit.

The purpose and use of the various portions of the system may be best discussed individually.

2.1 Instrument Jack Board

This board, Fig. 2, which is 14 in. wide by 10 ft in length is mounted on the wall of the Control Room. It contains 6 rows of duplex jacks. Five of these rows contain (a) 96 jacks connected by paired copper leads to junction boxes in the various laboratories and (b) 12 jacks for connection to chromel-alumel compensation thermocouples mounted in these junction boxes. Fig. 3 indicates the purpose of the various jack connections on this board. Fig. 4 is a schematic diagram which shows the location of the junction and jack boxes and also lists the input circuits currently available in the various buildings. The sixth or "instrument" row of jacks contains, in addition to the 96 jack connections, 12 jacks connected by chromel-alumel wire to the input circuits of the 8 potentiometric recorders and the four potentiometric indicators. Each of the 96 jacks in this row is connected to:

1. the potentiometric indicators through manual switches. These switches have an "off" position which permits their complete removal from the jack board.

2. the eight potentiometric recorders. Each recorder is a 12-channel unit which scans in sequence the 12 input circuits and records the data in the form of a temperature-time record.

3. the input scanning switch of the digital recording unit.

It will be readily seen that by use of this jack board and a supply of jumper lines and plugs, any thermocouple input circuit may be connected to any measuring circuit jack connection. In this way, it is a rather simple matter not only to connect geographically remote laboratories for recording and measuring purposes, but also to achieve great flexibility in the manner in which connections are made.

2.2 Potentiometric Recorders

These units, Fig. 5, are standard commercial 12-point recorders modified with a special input circuit. They are calibrated for use with chromel-alumel thermocouples and have temperature ranges and print cycle times listed in Table 1.

2.3 Potentiometric Indicators

These 4 instruments, Fig. 2, are connected through a 2-pole, 24-position switch, with an additional "off" position, in parallel with the lines to the 2 other readout systems. These indicating units, also calibrated for use with chromel-alumel thermocouples (see Table 1), were intended and have been used for manual data readout purposes. Since, when used they are placed in parallel with the recording potentiometric instruments, there is the possibility of feedback between instruments when a common thermocouple circuit is being scanned. Because of this, personal judgment must be employed during their use. These indicating instruments should always be in the "off" position during operation of the digital recording unit.

2.4 Modified Input Circuit

The modified input circuit used with these recorders and indicators is shown in Fig. 6. This circuit is provided to develop an emf correction,, inserted in series with the temperature signal, to compensate for differences in temperature of the thermojunctions formed at the potentiometers and at the junction or jack boxes in the various laboratories due to the use of copper extension leads. These leads were used for purposes of economy, but also to reduce the resistance of the lines which, in many cases, are as long as 300 ft.

This type of temperature compensation has proved quite adequate for the needs involved. In applying it, the only significant modification to the recording instruments is the use of a heavy metal box as an enclosure for the input terminal board on multi-channel instruments. This was found necessary to reduce a slight temperature differential across the width of the board.

2.5 Automatic Scanning and Digital Recording System

This unit, Fig. 7, permits automatic recording of up to 100 different thermocouple or millivolt signals. The scanning can be either manually controlled or automatically programmed at the rate of one channel per

second. Provision is incorporated for programming the channels to be recorded (or skipped) and selection of either a temperature or millivolt readout. Direct indication of temperatures with the use of chromel-alumel thermocouples is provided in the range of 0-1400°C with an accuracy of ±4°C. Millivolt signals may also be measured over the range of 0-14.00 mv with an accuracy of ±0.04 mv. The balancing time of the measuring potentiometer is on the order of 0.5 sec. The unit is built to permit scanning the 96 jack board circuits with initiation signals (or scan cycle periods) of 1/2, 1, 5, 10, 30, or 60 min. Provision is also included to completely remove the measuring circuit from all input leads in the standby or 00 channel position. In this position, a calibration signal is measured and printed out along with time at the start of the scan cycle. Circuit diagrams and further description of the operation of this unit are included in Appendix 1.

2.6 Furnace Program Control Unit

This unit, Fig. 8, is completely separate from the data measuring and recording circuit, and is fitted with its own 12-jack input plug board. This board permits input either of a single or of multiple thermocouples signals to the measuring circuit. If multiple inputs are connected, the internal circuitry of the panel is such as to effectively connect these inputs in parallel through 470 ohm swamping resistors. This permits development of an emf representative of the average of that of the individual inputs. The potentiometric measuring circuit compares the input signal with a self-generated signal corresponding to the time temperature relationship which it is planned to follow. The measuring circuit of this unit is of the high input resistance type and, as a result, does not present any significant load to the input signal. The correction signal generated is fed to a motorized valve in the air or gas supply lines of the various fire endurance test furnaces. In this manner the control unit programs the time-temperature conditions to be developed during furnace operation. Since the unit is frequently used with 12 furnace temperature input signals in parallel, failure of one or more thermocouples may cause an erroneous average signal, provision has been included to periodically open each of the input circuits sequentially on a one-minute cycle. Thus, if any thermocouple is providing a temperature signal significantly different from the average of the others, this will be evident from the shape of the recorded record. The circuit diagram is shown in Fig. 9.

Further description and instructions on this control unit are included in Leeds and Northrup publications as follows:

a. Model S, Type G 60000 Series Recorder, Direction Book 77-10-5-1.

b. Series 50 Electric Control System, Direction Book 77-33-1-12.

c. Series 50 Control Drive Mechanisms, Direction Book 77-9-1-5.

d. Control Drive Mechanisms, Direction Book 77-9-1-2.

Starting procedures for operation of each of the fire test furnaces and the appropriate program control unit settings are listed in Table 3.

APPENDIX

Automatic Scanning and Digital Recording System

The operation of the automatic scanning and digital recording system is summarized in the Datex Instruction Manual for System 14650-01 dated April 1960 and the following: Schematic Operational Diagram (Fig. 10), Scanning and Control Circuit Diagram (Fig. 11), Relay and Switch Complement (Table 2), Leeds and Northrup Instruction Manuals for High Speed Model S, Type G, Speedomax Recorder and Leeds and Northrup Dwg. No. H-SSS-442-C-10 for the measuring and motor circuits.

A. Automatic Scanner

The heart of the automatic scanner consists of two permanent magnets supported one above the other on the twin arms of a 100-tooth solenoid-operated ratchet armature. A total of 200 magnetically-operated mercury-wetted contact switches are arranged in two circular tiers of 100 each. The switch capsules, Clare Co. Type HGX-1003 or equivalent, are sealed in glass, pressurized with hydrogen and potted within an impregnated paper tube. Each switch consists of two poles and is double-throw except that the armature is common to both poles. Each step of the ratchet armature actuates two switches, each of which opens a normally closed contact for channel identification and closes a normally open contact for the input signal. Mercury-wetted switch contacts require contact protection in the form of the series resistor-capacitor networks shown in Fig. 11 for the portion used for relay switching.

B. Description of Controls

1. Relay Chassis

   a. Upper indicator shows channel being scanned.

   b. Lower indicator shows type of signal being measured °C or mv. Provision is included for later adding visual digital signal readout.

   c. "Temperature"-"millivolt" switches control type of signal. Temperature will be read out unless the tens and unit switch corresponding to the circuit being scanned are in the millivolt position (right). On scan position, No. 99, readout is always that of temperature compensator in test area being used. On position No. 00, a 10-mv signal is always read. These two signals serve as a check of operation of the system. Failure or erroneous indication of either signal should be checked prior to use of system.

d. "Record"-"No Record" switches control the scanning operation. Signal will be measured on all channel positions except when the tens and unit switch corresponding to circuit being scanned are set to "no record" position (right). This provides a fast-action run past those channel positions not required to be measured. Switches cannot be set to skip channel Nos. 99 and 00. These are used for system operational check.

e. Function Selector Switch determines the type of system operation.

(1) "Clock" - Printout occurs on any preset channel at periods depending on setting of system readout timing control switch (1/2, 1, 5, 10, 30 or 60 minutes).

(2) "Manual" - In this position, the scanning stepper may be set to any position desired by use of the manual ("jog") pushbutton. In this position no skipping or fast action run occurs and signal is printed at each scan position.

(3) "Program" - In this position, the initiation of readout is controlled by system readout timing switch on Digital Clock. Channels are scanned and recorded as programmed on temperature, millivolt and record, no-record switches. Scanning stops after print of compensator temperature at position No. 99. Carriage returns and is ready to start new line with print of 00. Scanning recommences as programmed.

(4) "No Print" - System performs as under program except that no print takes place.

(5) "Run" - System performs as described for program, but scanning is continuous and clock initiation is not required for printing No. 00.

f. "Jog" Push Button is only operative with function selector set on manual.

g. "Carriage return" push button causes carriage return on suceeding print command. Button ineffective unless depressed when print cycle starts.

h. "Power" switch controls 28 V DC supply furnishing power for relays and scanner.

2. Digital Clock (DC-106-4)

   a. System readout timing selector is used for selecting time at which scanning is initiated on "program" or readout period when on "clock."

   b. "Time set" push buttons can be used to reset clock to zero or any other desired time setting.

3. Leeds and Northrup Self-Balancing Potentiometer

   a. "Record" switch connects potentiometer and servo balance system for readout. This switch should be turned off if system continues drive either up or down scale.

   b. "Power" switch controls power to instrument.

   c. "Chart" switch inside instrument door is only used when graphical record is desired.

4. Control Chassis (K-106-111)

   a. "Power" switch controls power to instrument.

   b. "Record" button provides a means for actuation of printer without scanning.

5. Data/Log Printer (MC-203-39)

   This is a modified bookkeeping machine made by the Monroe Calculating Machine Company, Inc. Contains conventional means for supplying paper, adjusting carriage movements, etc.

C. Operating Sequence with Function Selector Switch on "Program"

(See Fig. 10 and Datex Instruction Manual)

1. Contact closure in digital clock energizes R-105 which locks in through its own contacts.

2. Next contact closure from one second clock energizes R-102. This breaks lock-in circuit of R-105, closes print contacts, and energizes stepper solenoid.

3. Print contact closure energizes relay K-122 in control chassis. This closes relay K-120 briefly, thus storing analog signal. Closure of relay K-122 also operates print solenoid on printer and digitized signal to digital solenoids through contacts 12 and 13 on relays K-101 to K-114. Remainder of print cycle is mechanically completed.

4. One second clock contacts open releasing R-102 permitting arm on scanner to step to next position.

5. On completion of printer operation contacts on printer open releasing relay K-121 which had previously locked in from operation of the carriage return indicate switch on printer. Release of this relay prevents further print of time signals until another carriage return occurs.

D. Precautions

1. When using the automatic scanning and digital recording system, all four of the manual scanning switches for the indicating potentiometers should be in the "off" position. If the manual switches and indicating potentiometers are to be used, the scanner should be stopped in position 00. In this position the scanner potentiometer will be connected to a reference voltage source quite independent of the jack board and the carriage return relay will not be energized.

2. The scanner should not be allowed to remain for lengthy periods in the No. 99 position as this leaves the carriage return relay energized and could possibly cause overheating and resulting damage.

3. Since both scanner and individual Brown potentiometers are connected in parallel by the wiring in the jack board, it is important for achieving accuracy in recorded data that no parallel input connections be made between two or more Brown recorders. This should not imply any problem with parallel connection of the inputs of any single recorder. This restriction is also not necessary when compensating thermocouple connection jumpers are not connected for the recorders involved.

4. Failure of the digital recording system to provide as signal of 10.00 in position 00' should be considered as evidence of some malfunction of the system and thus require maintenance.

E. Trouble Shooting Chart

Symptom	Possible Cause and Cure
1. System does not operate.	1. Check power connections and switches on each section.
2. Recording system operates, but no signal on °C.	2. Check compensating thermocouple connection. Check "record" switch on L & N potentiometer. Check thermocouple jumpers on instrument jack board.
3. Relay rack indicator lights do not operate.	3. Check fuse on relay chassis front.
4. All number lights superimposed on channel indicator.	4. Check fuse on 28 V power supply.
5. System OK, but no signal in standby condition (position 00).	5. Standardize relay R-104 locked in. Increase R-104 series resistance on relay chassis. Possibly caused by interchange of relays R-104 and R-105. Check 10 V power supply.
6. Carriage returns on 98 and 99 prints at start of new line.	6. Carriage return relay R-107 does not have enough series resistance. Adjust with potentiometer on relay chassis. This behavior can also result from condition described in item 12.

7. Scan cycle starts at time other than that set on digital clock.	7. Check diodes in digital clock rotary switch.
8. Scan cycle does not start.	8. Check that system readout timing switch on digital clock is not "off." Check that function selector switch on relay chassis is at "program," "no print," or "run."
9. Potentiometer drifts as with open circuit on No. 97 and 98.	9. This is normal operation since these two points are not used.
10. No channel identification printout on channel No. 00.	10. Normal operation.
11. Carriage returns but stops before reaching end of run, causing indentation of next print record.	11. Carriage returned from second or third column print positions. This improper operation is normal from such positions. Could be remedied by programming for return from later column. This difficulty is normal if manual carriage return were employed and button not released immediately on printer operation. Release return button earlier.
12. During program operation ratchet scanner stops operation and appears to be locked.	12. This fault is due to incorrect adjustment of armature stop on ratchet resulting in backward movement after being energized. If this occurs at position when prior point was set for no record then clock stops and ratchet remains locked in energized position. This can be remedied by adjusting stop on scanner ratchet relay armature.

TABLE 1

CHARACTERISTICS OF POTENTIOMETRIC RECORDERS AND INDICATORS

Recorder	Temp. Range (Chromel-Alumel) °C	Print Cycle Sec	Indicator	Temp. Range (Chromel-Alumel) °C	Full-Scale Balance Time Sec
A	0-1400	15	1	0-1400	12
B	0-1200	2	2	0-1200	12
C	0-1200	15	3	0-1200	12
D	0-1200	15	4	0-1200	12
E	0-1200	15			
F	0-1200	15			
G	0-500	15			
H	0-500	2			

TABLE 2. RELAY AND SWITCH COMPLEMENT

Relays

Designation	Description	Type*	Quan.	Chassis Location
R0....R9**	Switching Relays, Units	A	10	Relay
R00....R90**	Switching Relays, Tens	A	10	Relay
R101	Print Stop Relay	A	1	Relay
R102	Record Actuate Relay	B	1	Scanner
R103	Clock Motor Deactivate Relay	C	1	L & N
R104	Current Standardize Relay	B	1	Relay
R105	Program Start Relay	B	1	Relay
R106	Fast Run Stepper Relay	B	1	Scanner
R107	Carriage Return Relay	C	1	Relay
R108	Input Selector Relay	B	1	Relay
R109	Potentiometer Input Shorting Relay	C	1	L & N
R110....R117	Recorder Deactivate Relay	C	8	M - H

* A Clare RP-10883-G13, 6PST N.C., 2PST N.O.
B Potter and Brumfield, KRP-14DG,3PDT
C Clare HG 1043, SPDT

** Relays R0, R1,...R9 correspond to the channels whose units digits are 1, 2,...0. Relays R00, R10,...R90 correspond to the channels whose tens digits are 0, 1,...9, e.g., scanner in position 19 would de-energize relays R10 and R8.

TABLE 2 (Cont'd)

Switches

Designation	Description	Type	Quan.	Chassis Location
S0....S9A	Fast Run Switch	SPST Toggle	10	Relay
S00....S90A	Fast Run Switch	SPST Toggle	10	Relay
S0....S9B	Input Selector Switch	SPST Toggle	10	Relay
S00....S90B	Input Selector Switch	SPST Toggle	10	Relay
S100	Function Selector Switch	5 decks, 5 positions per deck, rotary	1	Relay
S101	Main Power Switch	DPST Toggle	1	--
S102	Auxiliary Power Switch	DPST Toggle	1	Relay
S103	Jog Switch	SPST Pushbutton	1	Relay
S104	Carriage Return Switch	SPST Pushbutton	1	Relay
S105	Recorder Disconnect Switch	SPST Toggle	1	Relay
S106	Carriage Return Disconnect Switch	DPST Microswitch	2	Printer
S107	Furnace Temp. Carriage Return Switch	SPST Toggle	1	Relay

TABLE 3. STARTING PROCEDURES FOR OPERATION OF FIRE TEST FURNACES

Furnace	Type of Control	Program Control Unit Settings	Starting Procedure
Wall Test (Bldg 64)	Manual-Gas	Not used.	1. Light gas pilots. 2. Use main gas valve for manual control.
Column Test (Bldg 65)	Program-Air	Recorder: Line: ON Control: ON Program: MANUAL, AUTO Control Unit: Type: MANUAL, AUTO Valve Opening*: 0 to 100 Prop. Band: 5% of Rec. Scale Reset: .2 repeats per min Rate Time: 0 minutes	1. Set "Recorder-program" and Control Unit Switches on "MANUAL". Set "Valve Opening" to 0. 2. Light gas pilots. (For floor furnace, also turn on switch for magneto-operated spark igniter plugs.) 3. Turn on air blowers. (Not applicable to two-foot slab furnace.) 4. Open main gas valve fully. 5. Turn on key switch for electric gas valve. 6. Increase "Valve Opening" setting until furnace burners ignite. 7. Throw "Recorder-program" and Control Unit Switches from "MANUAL" to "AUTOMATIC". (Not applicable to CS131-46.)
Floor Test (Bldg 67)	Program-Air	Same	
Two-Foot Slab (Bldg 68B)	Program-Gas	Same	
SS-A-118b or Deck Covering (Bldg 64)	Program-Air	Recorder: Same Control Unit: Type: MANUAL, AUTO Valve Opening*: 0 to 100 Prop. Band: 10% of Rec. Scale Reset: .1 repeats per min Rate Time: .1 minutes	
Fire Resistance Test CS131-46 (Columbia Curve) (Bldg 64)	Manual-Air (through control unit)	Recorder: Line: ON Control: ON Program: MANUAL Control Unit: Type: MANUAL Valve Opening*: 0 to 100 Prop. Band: 10% of Rec. Scale Reset: .1 repeats per min Rate Time: .1 minutes	

*Indicates valve position on "AUTOMATIC"; controls valve position on "MANUAL".

List of Illustrations

List of Tables

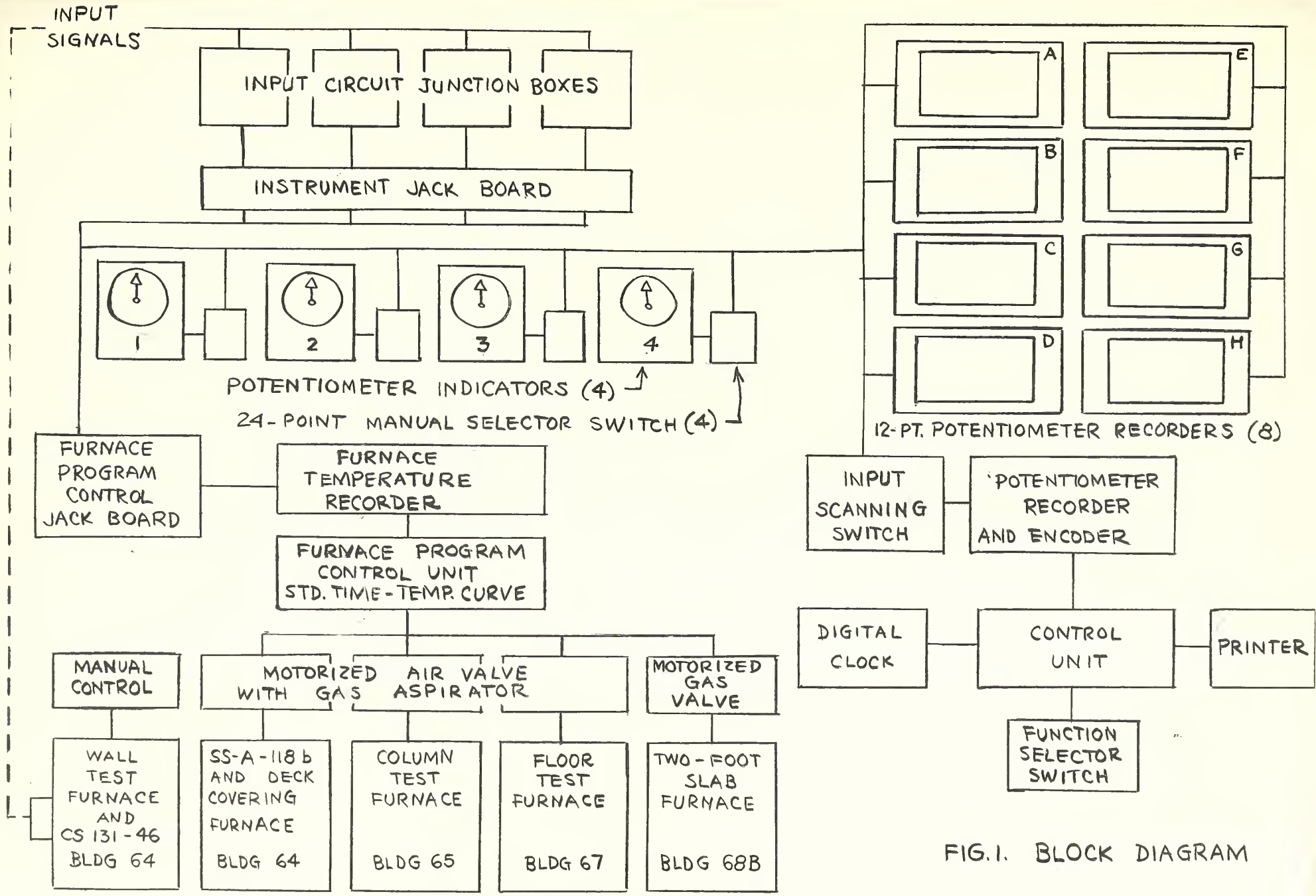


FIG. 1. BLOCK DIAGRAM

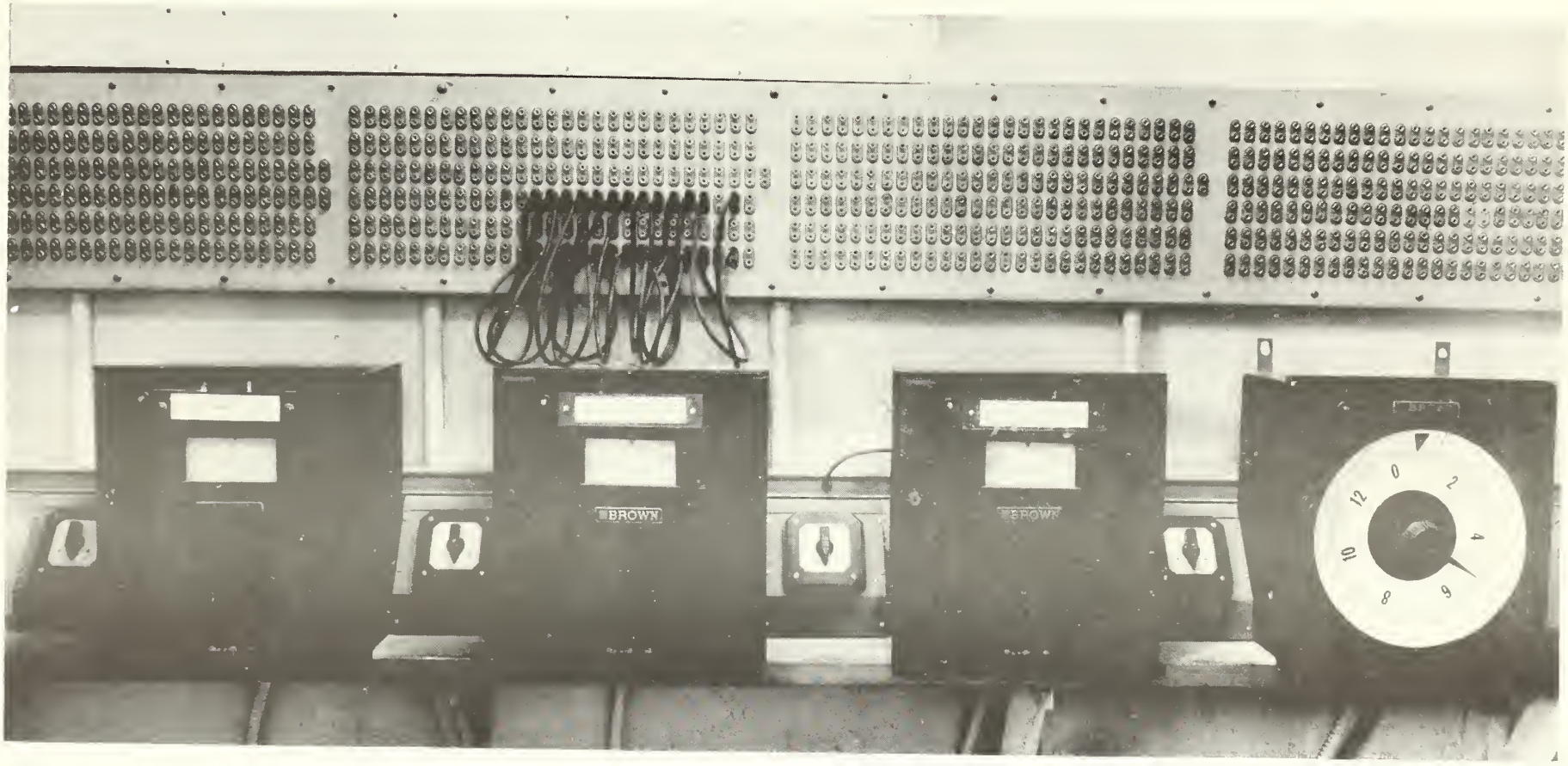


Fig. 2 Instrument Jack Board and Potentiometer Indicators

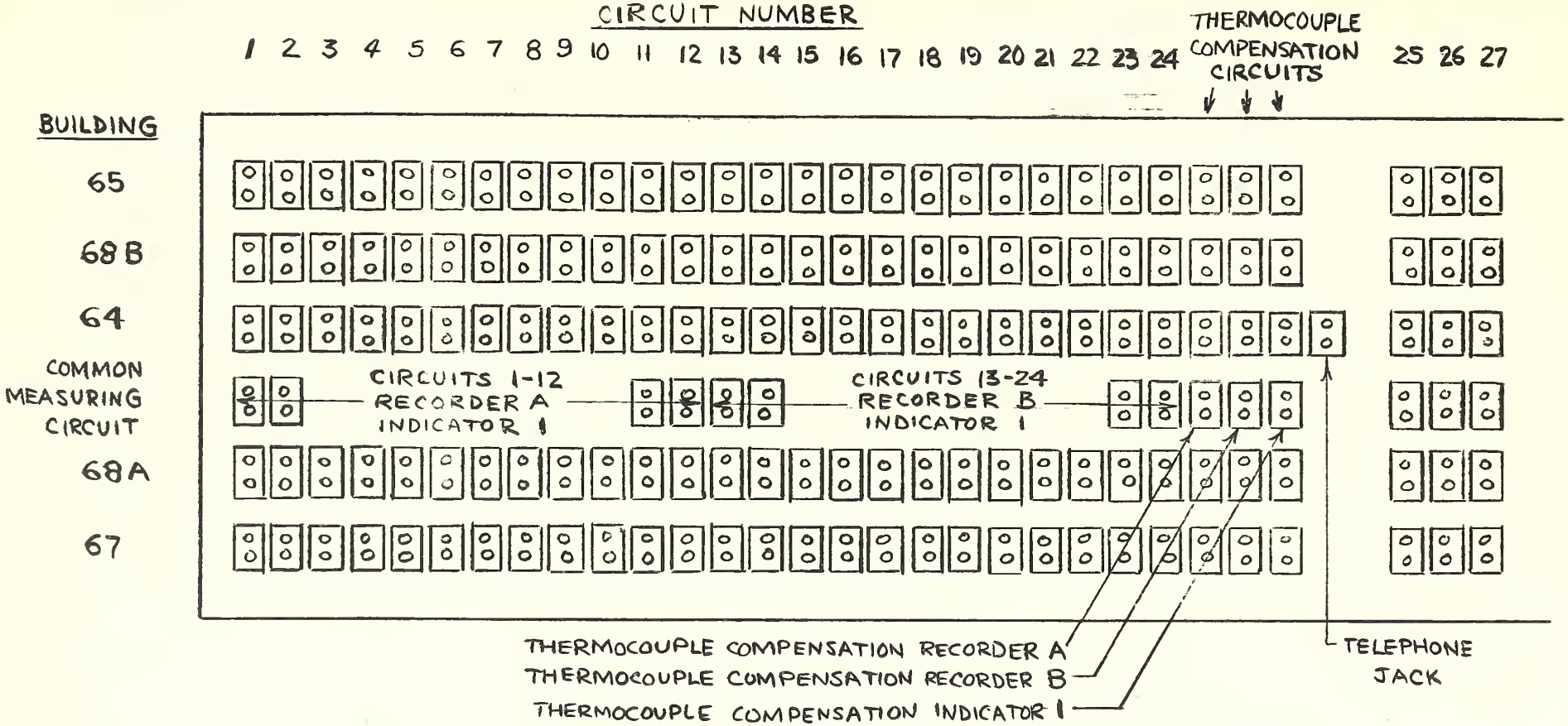
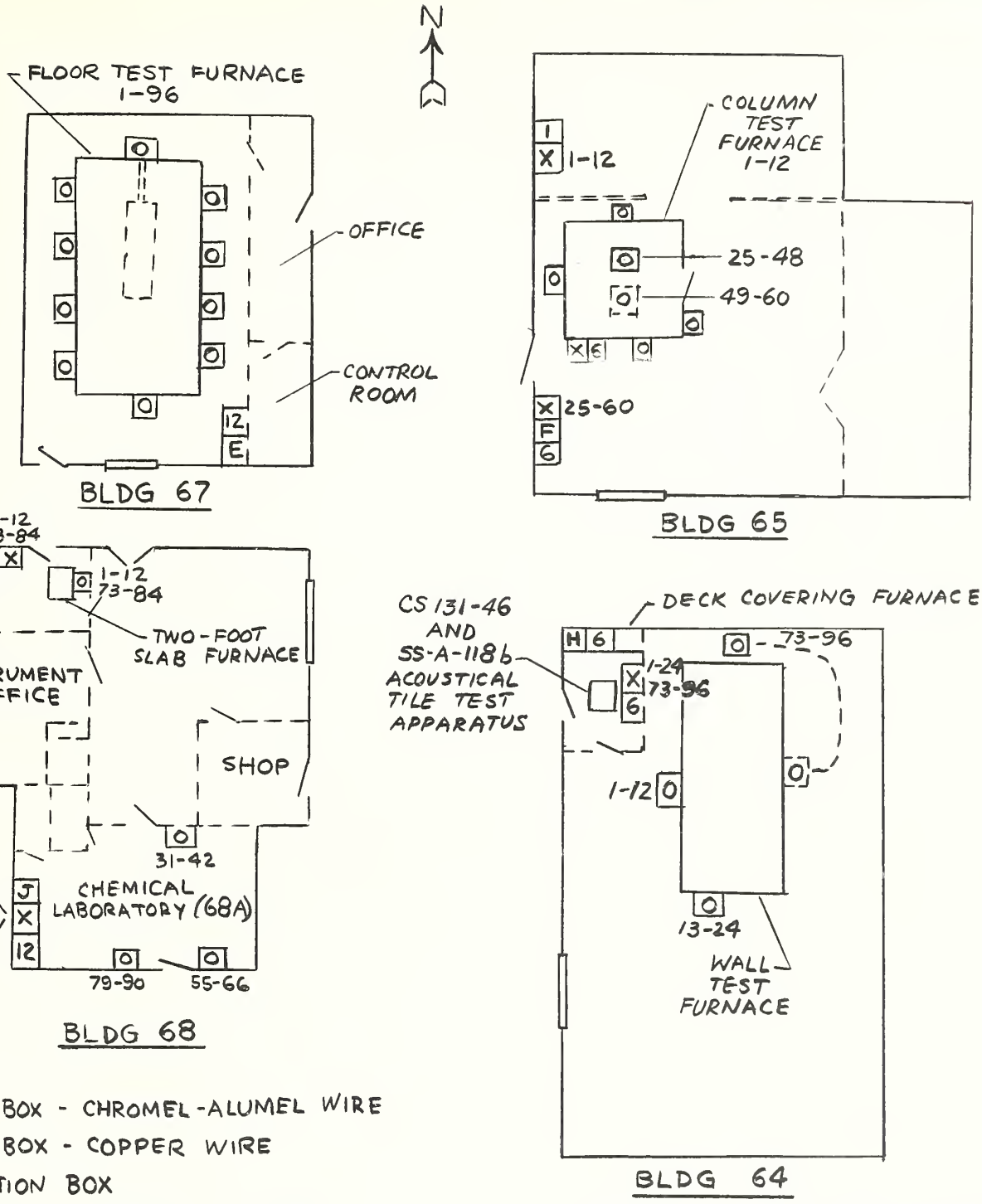


FIG. 3 INSTRUMENT JACK BOARD AND CIRCUIT CONNECTIONS



[O] JACK BOX - CHROMEL-ALUMEL WIRE

[X] JACK BOX - COPPER WIRE

[E] JUNCTION BOX

[6] NUMBER OF CHROMEL-ALUMEL COMPENATION CIRCUITS

ALL JUNCTION BOXES CONTAIN 96 CIRCUITS, INCLUDING THOSE NOT WIRED INTO JACK BOXES

BLDG	THERMOCOUPLE CIRCUITS WIRED INTO DUPLEX JACK BOXES
64	1-24, 73-96
65	1-12, 25-60
67	1-96
68A	1-6, 25-42, 49-66, 73-90
68B	1-12, 73-84

FIG. 4 SCHEMATIC LOCATION OF JUNCTION BOXES AND JACK BOXES

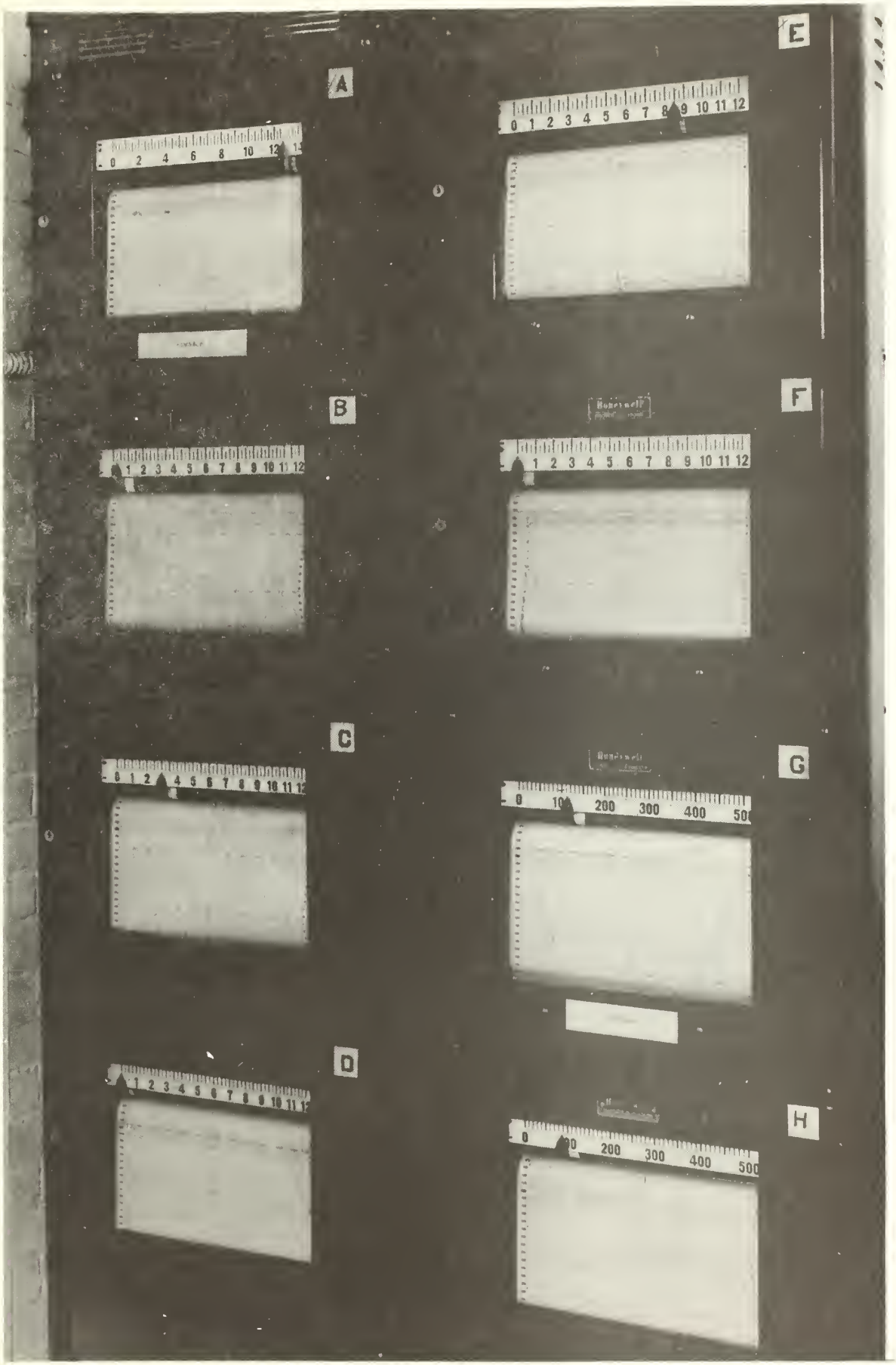


Fig. 5 Multiple-point Potentiometer Recorders

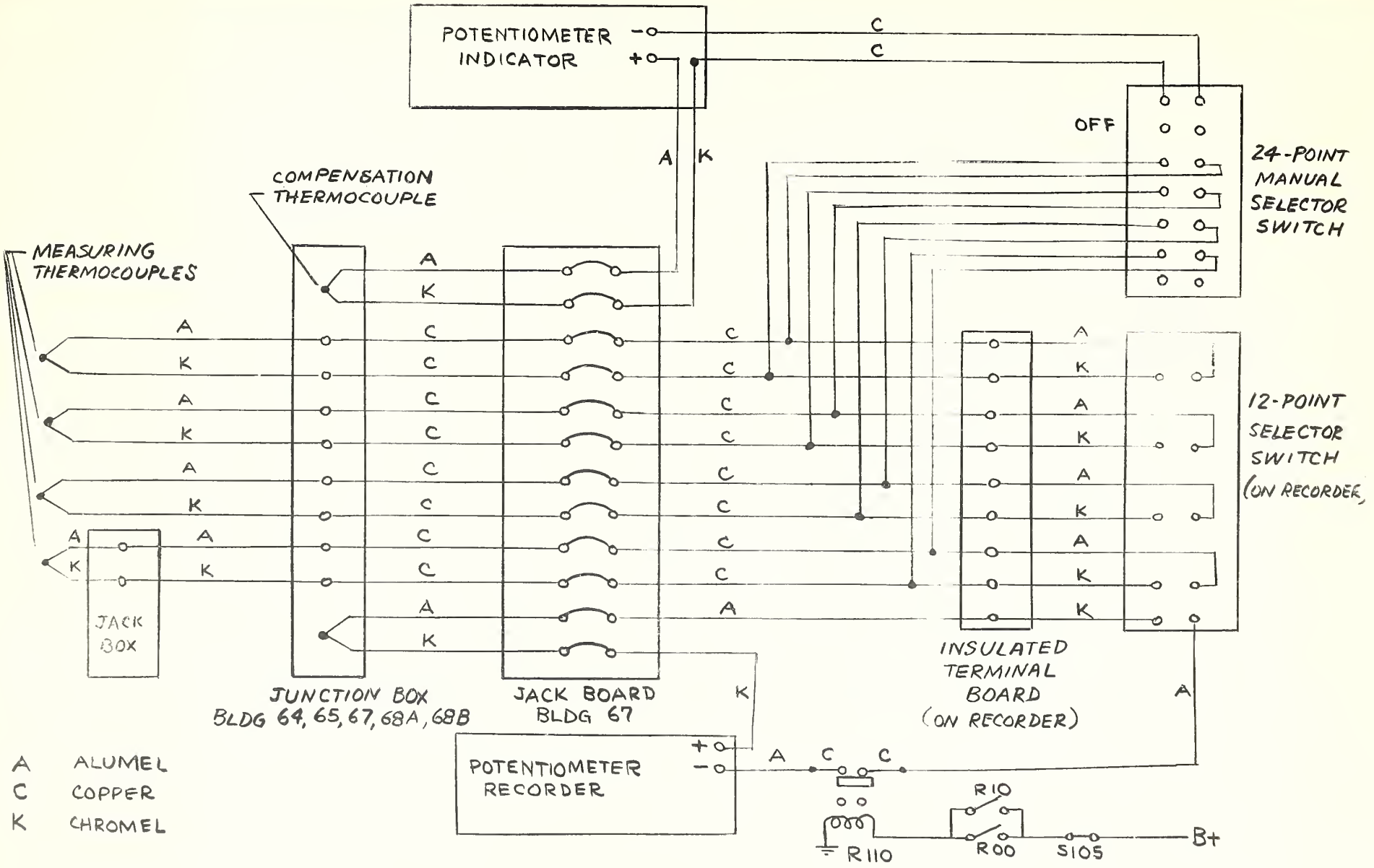


FIG. 6 THERMOCOUPLE INPUT CIRCUITS FOR POTENTIOMETER RECORDERS AND INDICATORS

Fig. 7 Automatic Scanning and Digital Record System

Fig. 8 Furnace Program Control Unit

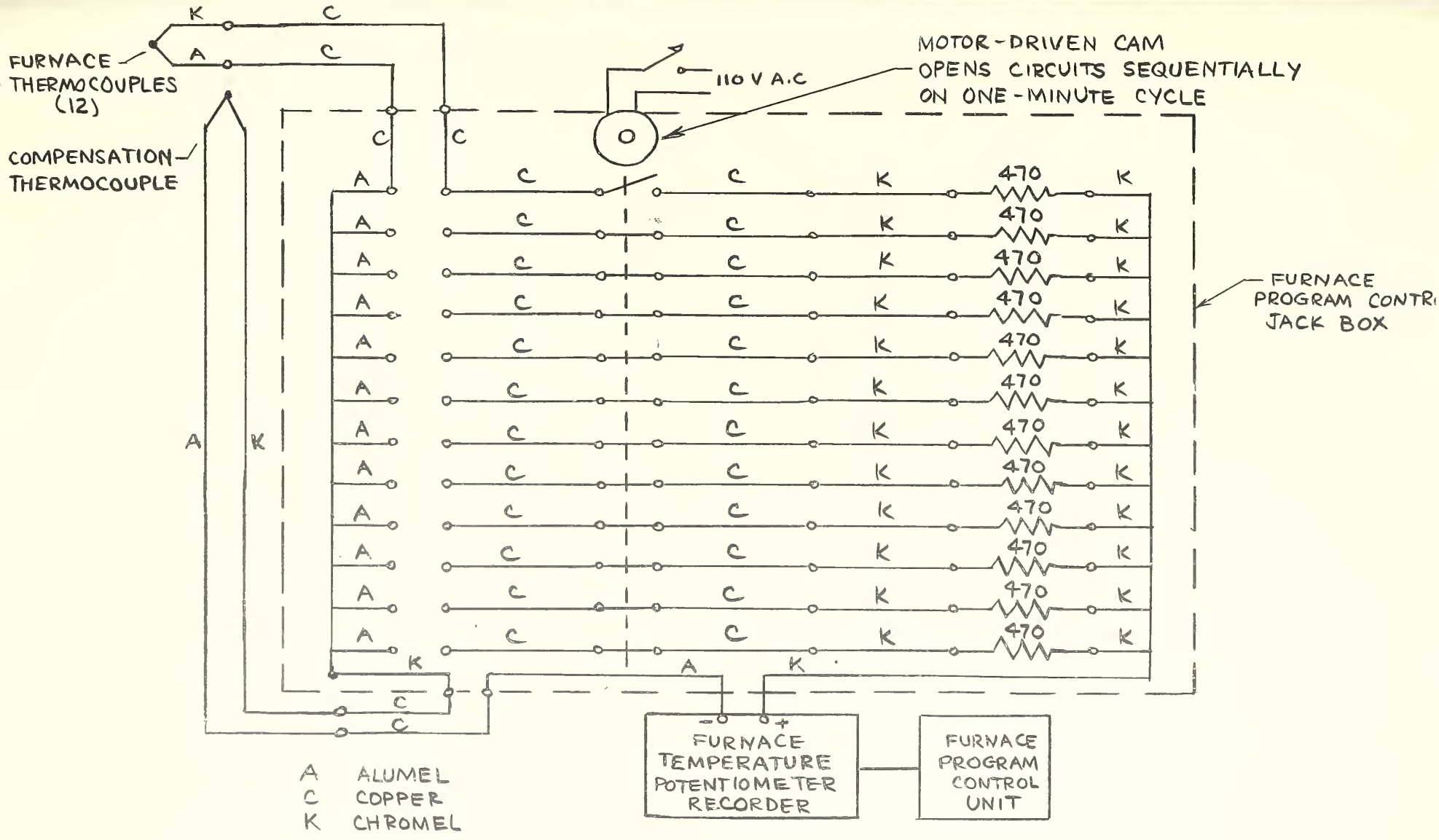


FIG. 9 THERMOCOUPLE INPUT CIRCUIT FOR FURNACE PROGRAM CONTROL

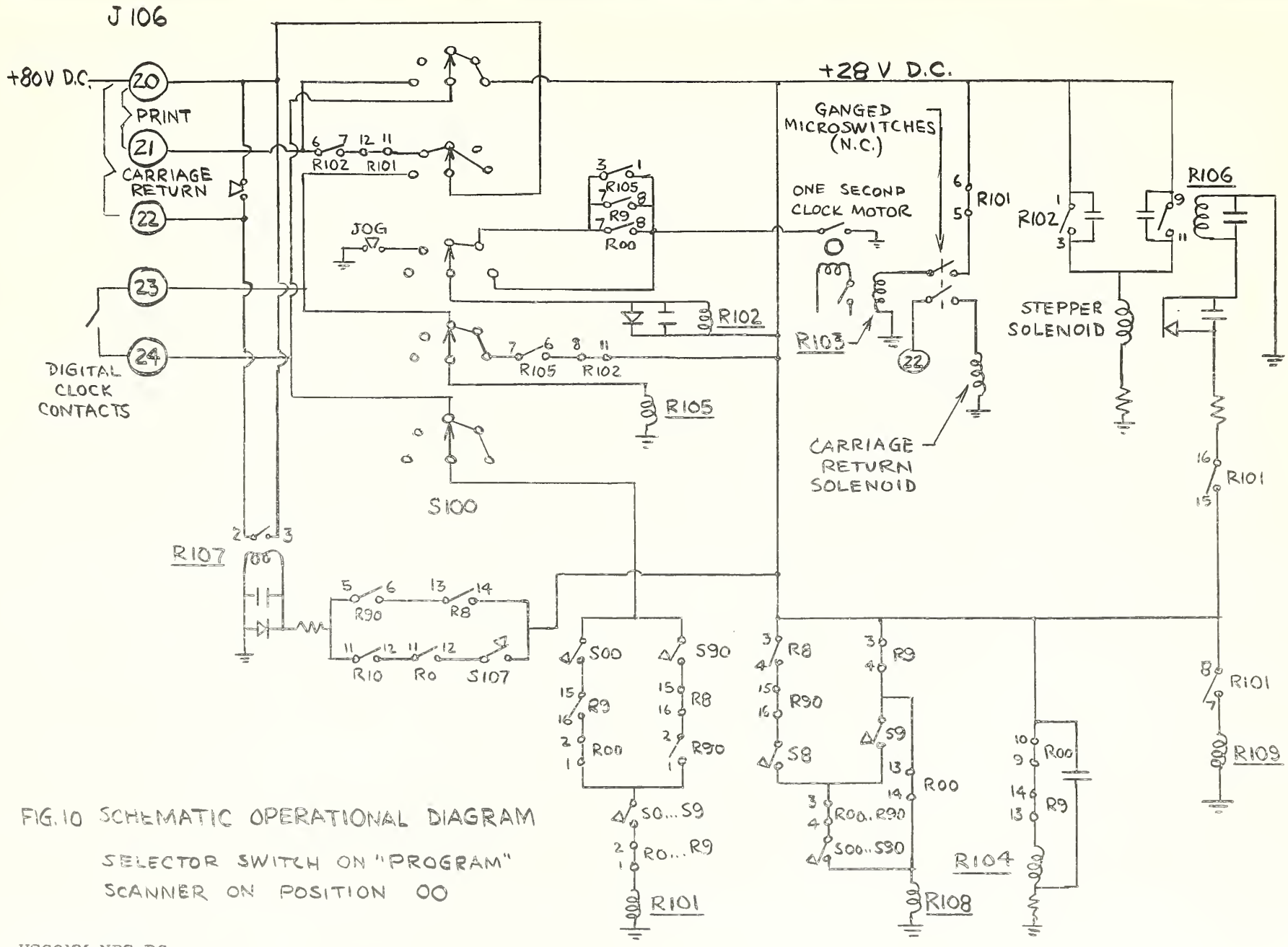
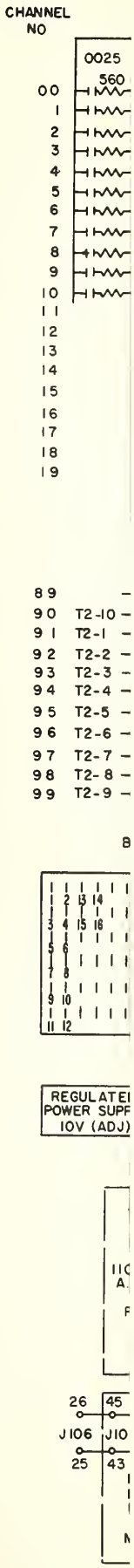


FIG. 10 SCHEMATIC OPERATIONAL DIAGRAM

SELECTOR SWITCH ON "PROGRAM"
SCANNER ON POSITION 00


CHANNEL NO
0025
560
00
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
89
90 T2-10
91 T2-1
92 T2-2
93 T2-3
94 T2-4
95 T2-5
96 T2-6
97 T2-7
98 T2-8
99 T2-9
REGULATEI
POWER SUPF
10V (ADJ)
26
45
J106
J10
25
43

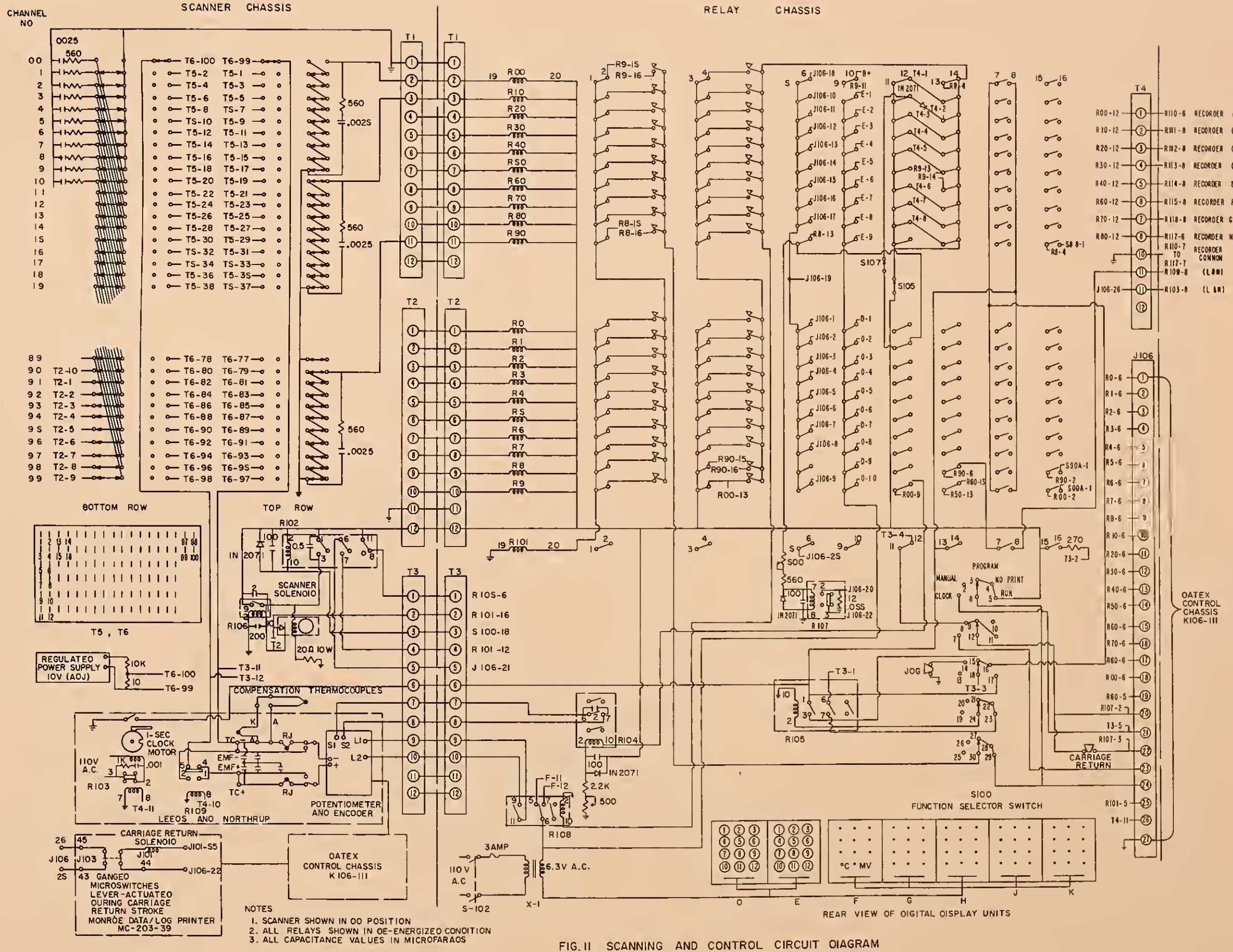


FIG. II SCANNING AND CONTROL CIRCUIT DIAGRAM

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

ELECTRICITY. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

METROLOGY. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

HEAT. Temperature Physics. Heat Measurements. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research. Equation of State. Statistical Physics. Molecular Spectroscopy.

RADIATION PHYSICS. X-Ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

CHEMISTRY. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

MECHANICS. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Combustion Controls.

ORGANIC AND FIBROUS MATERIALS. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

METALLURGY. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

MINERAL PRODUCTS. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

BUILDING RESEARCH. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

APPLIED MATHEMATICS. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

DATA PROCESSING SYSTEMS. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

ATOMIC PHYSICS. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics.

INSTRUMENTATION. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

IONOSPHERE RESEARCH AND PROPAGATION. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

RADIO PROPAGATION ENGINEERING. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

RADIO STANDARDS. High frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

RADIO SYSTEMS. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

UPPER ATMOSPHERE AND SPACE PHYSICS. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.


NBS